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Anatomic Knowledge and Perceptions of the Adequacy of Anatomic Education Among Applicants to Orthopaedic Residency

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Abstract

Background: The time dedicated to the study of human anatomy within medical school curriculums has been substantially reduced. The effect of this on the knowledge of incoming orthopaedic trainees is unknown. The current study aimed to evaluate both the subjective perceptions and objective anatomic knowledge of fourth-year medical students applying for orthopaedic residency.

Methods: A multicenter prospective study was performed that assessed 224 students during the course of their interview day for an orthopaedic residency. Participants provided demographic data and a subjective assessment of the quality of their anatomic education, and completed either an upper or lower extremity anatomic examination. Mean total scores and subscores for various anatomic regions and concepts were calculated.

Results: Students on average rated the adequacy of their anatomic education as 6.5 on a 10-point scale. Similarly, they rated the level of importance their medical school placed on anatomic education as 6.2 on a 10-point scale. Almost 90% rated the time dedicated to anatomy as good or fair. Of six possible methods for learning anatomy, dissection was rated the highest. On objective examinations, the mean score for correct answers was 44.2%. This improved to 56.4% when correct and acceptable answers were considered. Regardless of anatomic regions or concepts evaluated, percent correct scores did not reach 50%. There were no significant correlations between performance on the anatomic examinations and either prior academic performance measures or the student's subjective assessment of their anatomic education.

Conclusions: Current students applying into orthopaedic residency do not appear to be adequately prepared with the prerequisite anatomic knowledge. These deficits must be explicitly addressed during residency training to produce competent, safe orthopaedic surgeons.

The study of human anatomy has for centuries been an indisputable pillar of medical education. While relevant to all specialties, instruction in anatomy is an essential prerequisite to surgical training. Despite its importance, there has been a near-universal reduction in time allocated to studying this discipline across medical schools worldwide. Because of an ever-expanding breadth of medical advances that necessarily vie for time among traditional curricular staples and an evolution in education theory away from lectures and the perceived burden of isolated facts, instruction in human anatomy has been a common casualty during the trimming of medical education in the past two decades.^{1–10} This has occurred despite numerous published reports documenting the concerns among anatomists, students, young doctors, and established clinical faculty about the adequacy of contemporary anatomic education.^{2,6,7,11–13}

Equally concerning during this period of curricular change has been an almost complete lack of objective measurement to determine the effects of these changes and whether current standards of anatomic instruction remain adequate. The purpose of the current study is to (1) objectively measure the anatomic knowledge of fourth-year medical students preparing to enter into orthopaedic residency, (2) subjectively assess the students' perceived adequacy of their anatomic education, (3) assess the students' preferred methods of anatomic instruction, and (4) assess for

correlations between students' prior academic performance and anatomic knowledge and subjective adequacy of anatomic education and anatomic knowledge.

Methods

A convenience sample of applicants to four orthopaedic residency programs (University of California, San Francisco; University of Washington; Baylor College of Medicine; and University of Florida Jacksonville) was evaluated during the 2014–2015 interviewing cycle. Applicants were approached during the course of their interview day and asked to participate. It was made clear that the study had no bearing on the residency selection process, and the applicants were free to refuse participation. No identity information was recorded.

All data were gathered on written answer keys completed by the students. Questions regarding each student's demographics, subjective assessment of their anatomic education, preferred method of instruction, and objective measures of their anatomic knowledge were listed both on the written answer key and on a power point presentation of the questions provided to the group of consenting students simultaneously.

Data Collected

Demographics

Basic demographic data as well as commonly used measures of academic performance were gathered. The data included the following:

1. Basic demographics: age, sex, and race
2. Measures of academic performance: current medical school, additional degrees (MS, MBA, JD, and PhD), MCAT [Medical College Admissions Test] score, and USMLE [United States Medical Licensing Examination] Part I and II scores

Subjective Measures of the Adequacy of Anatomic Education

These data were collected before their exposure to the objective anatomic questions such that the student's perceived performance on the specific items on the objective examination did not influence their subjective scoring of their anatomic knowledge.

1. Students were asked to rate their perceived adequacy of their anatomic education using a 10-point scale, 1 being a completely inadequate education, 5 being merely adequate, and 10 being an ideal education.
2. Students were asked to report on the amount of time dedicated to the study of human anatomy during their medical school curriculum. Options included the following:
 1. No dedicated time
 2. Poor amount of dedicated time: completely insufficient to allow an adequate understanding of the material
 3. Fair amount of dedicated time: insufficient to allow complete understanding but enough to have reviewed basic materials/concepts

Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, and patent/licensing arrangements) that might pose a conflict of interest in connection with the submitted article.

Ethical review committee statement: The enclosed work was reviewed and approved by UCSF's ethics review board.

Dr. Dawson or an immediate family member has stock or stock options held in Lineage Medical—Orthobullets. Dr. Firoozabadi or an immediate family member serves as a paid consultant for Smith & Nephew. Dr. Lee or an immediate family member serves as a board member, owner, officer, or committee member of the American Society for Surgery of the Hand. None of the following authors or any immediate family member has received anything of value from or has stock or stock options held in a commercial company or institution related directly or indirectly to the subject of this chapter: Dr. Toogood, Dr. Shaw, Dr. Nussenbaum, Dr. Acosta, and Dr. Perkins.

4. Good amount of time: sufficient to allow complete review of all important topics
 5. Excellent amount of time: sufficient to allow mastery of all important topics
 6. Too much dedicated time
3. Students were asked to rate the level of importance their medical school placed on human anatomy using a 10-point scale, 1 being completely unimportant, 5 being neutral importance, and 10 being extremely important.

Assessment of Preference for Methods of Anatomic Instruction

Students were asked to rate the importance of six common methods of anatomic instruction. A score of 1 indicated the most important method of instruction and a score of 6 the least.

1. Methods of instruction:
 1. Dissection of cadavers by students
 2. Inspection of prosected cadavers
 3. Didactic teaching/lectures
 4. Use of models (plastic models, skeletons, etc.)
 5. Use of computer-aided learning (digital atlas)
 6. Teaching of living (topographic) and radiographic anatomy

Students were also asked to report which of the above-mentioned methods were available during their medical school curriculum.

Objective Measure of Anatomic Knowledge

To avoid duplicated assessments of students interviewing at the four institutions and the possibility of the applicants, reviewing the answers to questions previously asked, participants were asked to self-report if they had previously participated at a prior study site. All items were open responses (as opposed to multiple choice) to avoid correct answers

made by chance and to better test the students' recall memory (as opposed to recognition memory).

To the knowledge of the lead author, (P.T.), there was no previously validated anatomic test designed to evaluate the musculoskeletal knowledge of medical students applying into orthopaedics. As such, upper and lower extremity examinations were created for the purposes of this study. These examinations were created based on a pilot study of orthopaedic residents conducted at the University of California, San Francisco. This pilot study consisted of several hundred questions given over multiple sessions to most of the 35 residents at this program. From the data of this pilot study, the final objective questions described below were selected. The chosen questions were selected based on multiple factors. From the pilot study, those questions that were near-universally answered correctly (eg, identifying the femoral head) were excluded. Similarly, those questions that were more commonly answered incorrectly or answered correctly only by the more senior residents (eg, identifying the posterior inferior tibiofibular ligament) were also excluded. From the list of remaining questions, the final examination questions were selected so that all basic anatomic areas and concepts would be represented and that the final number of questions could be reasonably answered in 15–30 minutes.

There was a total of 35 upper extremity questions and 30 lower extremity questions. The questions were designed to assess functional, osseous, ligamentous, muscle/tendon, and neurovascular concepts within five anatomic regions of the upper (shoulder, arm, elbow, forearm, and hand/wrist) and lower (hip/pelvis, thigh, knee, leg, and foot/ankle) extremities (Tables 1 and 2).

Answers to individual questions were graded as correct, incorrect, or acceptable. Acceptable answers were those that, while not completely cor-

rect, did demonstrate some level of anatomic knowledge, for which credit was given. As an example, students were asked to list the functions of the rectus femoris. The correct answer is hip flexion and knee extension. An acceptable answer was providing one but not both functions. As such, the tests were then later scored twice. The first score was the percent correct; the second score was the percent correct and the percent acceptable.

Statistical Analysis

Basic descriptive statistics were used to report the demographic, subjective, and objective data. Pearson coefficients were used to look for correlations between prior academic performance (MCAT and USMLE I & II scores) and anatomic knowledge. Internal consistency reliability of the upper and lower extremity examinations was evaluated with Cronbach coefficient alpha.

Results

A total of 238 written examinations were completed. One individual reported taking an upper extremity examination at two sites. The second examination for this individual was discarded, leaving 237 examinations. Thirteen additional students stated that they had taken both the upper and lower extremity examinations at different institutions. Thus, although 237 examinations were scored for this study, this represents the work of 224 individuals from at least 92 different North American medical schools (not all applicants reported the identities of their medical schools). Electronic Residency Application Service statistics for the 2014–2015 application cycle indicate that 1,582 individuals applied into orthopaedics. The current study sample, therefore, includes approximately 14% of all individuals who submitted an application for an

Table 1**Upper Extremity Questions**

	Shoulder	Arm	Elbow	Forearm	Hand/Wrist
Function	Action of teres major?	Action of biceps?	Name the two motions that occur at radiocapitellar joint	Action of flexor digitorum superficialis?	Function of the lumbricals
Osseous	Identify supraspinatus fossa	Name structures in spiral groove	Identify coronoid	What wraps around Lister tubercle?	Identify hamate
Ligamentous	Identify coracoacromial ligament	None	(1) Identify annular ligament (2) Identify medial collateral ligament	None	What is the name of the ligament released for carpal tunnel syndrome? What are the contents of the carpal tunnel?
Muscle/tendon	Identify teres minor and provide innervation	(1) Name origins of long and short heads of biceps 2) Identify coracobrachialis and provide innervation	Identify anconeus	(1) Identify flexor digitorum profundus and provide innervation (2) Identify abductor pollicis longus and provide innervation	(1) Innervation of thenar muscles (2) Origin of lumbricals
Neurovascular	Identify musculocutaneous nerve arising off the brachial plexus	Name structures that go through quadrilateral space	Ulnar nerve passes through heads of what muscle to leave cubital tunnel?	Name two major branches of radial nerve in the forearm	Which artery usually provides the dominant arterial supply to the superficial palmar arch?

orthopaedic residency and likely a significantly higher percentage of individuals who actually interviewed.

Demographics

Basic demographics and prior academic performance are listed in Tables 3 and 4.

Subjective Measures of the Adequacy of Anatomic Education

When asked to rate the adequacy of their anatomic education on a 10-point scale, the mean response was 6.5, indicating a score somewhat better than an adequate score of 5. Similarly, when asked to eval-

uate the level of importance their medical school placed on their anatomic education, the mean response was 6.2. Rating the amount of time that they had spent in medical schools on human gross anatomy, 50% rated it as good, 39% fair, 6% excellent, 5% poor, and a single respondent indicated that no time had been set aside for anatomic education. Of note, no students rated the amount of time spent on anatomy as "too much."

Assessment of Preference for Methods of Anatomic Instruction

When asked to rate six common methods for learning anatomy as 1

through 6, dissection was rated as the most favored method, followed by didactic lectures and then prosection. Plastic models, radiographic and topographic anatomy, and computer simulations were rated as less favorable (Table 5).

Objective Measure of Anatomic Knowledge

The mean percent correct for all answers to both the upper and lower extremity examinations for all students was 44.2%. This improved to 56.4% when both correct and acceptable answers were considered.

Table 2

Lower Extremity Questions					
	Hip/Pelvis	Thigh	Knee	Leg	Foot/Ankle
Function	What are the functions of the rectus femoris?	What is the function of the sartorius?	What is the primary constraint to valgus stress?	(1) What is the function of the soleus? (2) What is the function of the gastrocnemius?	What motion occurs at the subtalar joint?
Osseous	Identify the ischial spine	Identify linea aspera	None	None	Identify the cuboid
Ligamentous	Identify sacrotuberous ligament	None	Where does the anterior cruciate ligament insert on the femur?	None	1) Identify anterior inferior tibiofibular ligament 2) Identify calcaneofibular ligament
Muscle/tendon	Where does the iliopsoas tendon insert?	What muscles contribute to the pes anserinus?	What structure inserts onto Gerdy tubercle?	Identify extensor digitorum longus	Identify the quadratus plantae
Neurovascular	What innervates the gluteus medius?	(1) Name the compartments of the thigh (2) Identify profundus femoris	What innervates the biceps femoris?	(1) Name the compartments of the leg (2) What provides the innervations to the tibialis anterior?	Identify nerves that provide sensation to each portion of the foot.

In addition to the mean total score, subscores for the various anatomic regions and anatomic concepts were also calculated (Figures 1 and 2). Regardless of the subscore considered, no area had a raw correct average of >50%. Scores of course improved when acceptable answers were included; however, most scores for the various subcategories remained between 50% and 60%, and the high for any category just surpassed 75%.

Various correlations were sought between students' objective anatomy scores and measures of their prior academic performance and perceived subjective evaluation of the adequacy of their anatomic education (Table 6). None of the tested measures correlated more than very weakly ($r > 0.2$).

The internal consistency reliability of the upper and lower extremity examinations was evaluated with

Cronbach coefficient alpha. This statistical test is designed to indirectly measure the degree to which a set of test questions measures a single unidimensional latent construct: in this case, knowledge of upper or lower extremity anatomic knowledge. The obtained coefficients were 0.83 for upper extremity examination and 0.80 for lower extremity examination, indicating that both examinations had good internal reliability.

Discussion

The importance of sound understanding of anatomy to practicing orthopaedic surgeons is indisputable; the profession simply cannot be performed safely without it. For decades, it has been the assumed responsibility of medical schools to provide students with the necessary

basic anatomic foundation on which to build during residency to make this safe practice possible. In the past several decades, however, there has been a dramatic reduction in the amount of hours dedicated to the study of human gross anatomy in medical schools worldwide.¹⁻¹⁰ The likely reasons for this included the ever-expanding breadth of medical advances that necessarily vie for time among traditional curricular staples, an evolution in education theory away from lectures and toward problem-based learning,^{1-3,7} and the perceived burden that isolated facts placed on students.⁶ Simultaneously, and directly due to this reduction in time allotted to human gross anatomy, there has been a precipitous drop in the perceived value of cadaveric dissection, which has frequently been substituted with prosection, the use of plastic

Table 3**Basic Demographics**

Age (Mean in Years)	27
Sex	
Male	86.5%
Female	12.7%
Race	
White	68.8%
Asian	13.9%
Other	6.4%
African American	6.3%
Hispanic	4.2%

Table 4**Prior Academic Performance: Additional Degrees**

MPH/MBA/MS	14.8%
PhD	1.7%
MCAT (mean)	32.2
USMLE Step I (mean)	248
USMLE Step II (mean)	253

MCAT = United States Medical Licensing Examination, USMLE = United States Medical Licensing Examination.

models, and computer-based simulation.^{1,5,7-10}

Despite worldwide, broad, sweeping curricular changes, there has been relatively little assessment of the consequences of this paradigm shift. The few existing published reports on anatomic education during this time of change suggest, however, that current methods may not be meeting appropriate standards.

Authors previously have reported on students' subjective perceptions of their anatomic education in modern curricula. Summarizing the results of several prior studies that took place at eight Dutch medical schools that had implemented a problem-based, learning-based curriculum, one review noted that students uniformly perceived deficits in their anatomic knowledge and that this was reflected in high anatomic-test failure rates.³ Similarly, authors from the United Kingdom investigated the opinions of "newly qualified doctors" and found that nearly half felt that they had received insufficient instruction in anatomy and that this was most strongly felt by those entering a surgical field.¹³ By contradistinction, educational researchers in South Korea noted that their students, who continued to be subjected to 50 hours of lecture and 120 hours of dissection, continued to regard their anatomic

education as adequate and dissection as essential.⁴

Other authors have similarly reported on objective measures of anatomic knowledge among contemporary students, residents, and clinicians, providing equally concerning results. Examining the scores on a musculoskeletal cognitive examination (which included more than just anatomy) taken by 334 volunteer students, residents, and staff physicians of multiple disciplines, prior American authors reported a mean score of only 57% and a mean passing score (>73.1%) of 21%.¹¹ Similarly, a group of 170 clinicians from the United States, Mexico, and five other Central or South American nations, most of whom were rheumatology fellows or attending physicians, recorded a mean score of 47% on an anatomic examination.¹²

In addition, a small group of recent authors has investigated the students' preferred method of anatomic instruction. Reporting on students from Australia, South Korea, the United Kingdom, and Germany, multiple authors have repeatedly shown that students consistently report their preference for traditional methods such as anatomic dissection over modern modalities such as models and computer simulation.^{1,4,5,10} In addition, when 112 professors of anatomy in the United

Kingdom were asked about their preferences, they too preferred dissection as the primary means of training.⁸

Given these limited but concerning reports produced in the wake of curricular change, it seems imperative to investigate the assumption that contemporary applicants to orthopaedic residencies come prepared with the expected basic anatomic knowledge.

The demographics of the 224 students that comprised this study's sample are likely typical of a contemporary orthopaedic applicant pool. Worth emphasizing, perhaps, is the significant level of prior academic achievement among this group. A large proportion of individuals had one or more advanced degrees in addition to their upcoming MD, and the mean test scores for the MCAT and USMLE I and II would be perceived as extremely competitive. Despite this high level of proven aptitude, the group's performance on basic anatomic questions was obviously poor. Such results emphasize what must be a true failure of the educational system these future surgeons find themselves in.

Students' subjective responses to the questions aimed at measuring their perception of their anatomic education, as opposed to other reports, present an additional hurdle. Students tended to rate their educational experience and their medical schools' emphasis on anatomy as more than adequate, and most rated the time dedicated to human gross anatomy as at least good, with few reporting it as poor. Despite this self-perception of preparedness, the students when tested appear dramatically under-prepared, perhaps suggesting an underappreciation for the importance anatomy will play in their chosen profession.

Also of interest to educators should be the preferred methods of instruction expressed by the students. It has

become increasingly popular to offer students alternative means to learn anatomy, exemplified by computer simulation. Such a modality avoids the time and cost of traditional dissection, prosection, and didactics; however, it does not achieve the same level of authenticity, and also likely provides less opportunity for repetition of key concepts. Long hours in the dissecting room and classroom may appear inefficient by today's educational standards; however, education may not be maximized with a focus on efficiency, and students in this study appeared to recognize this.

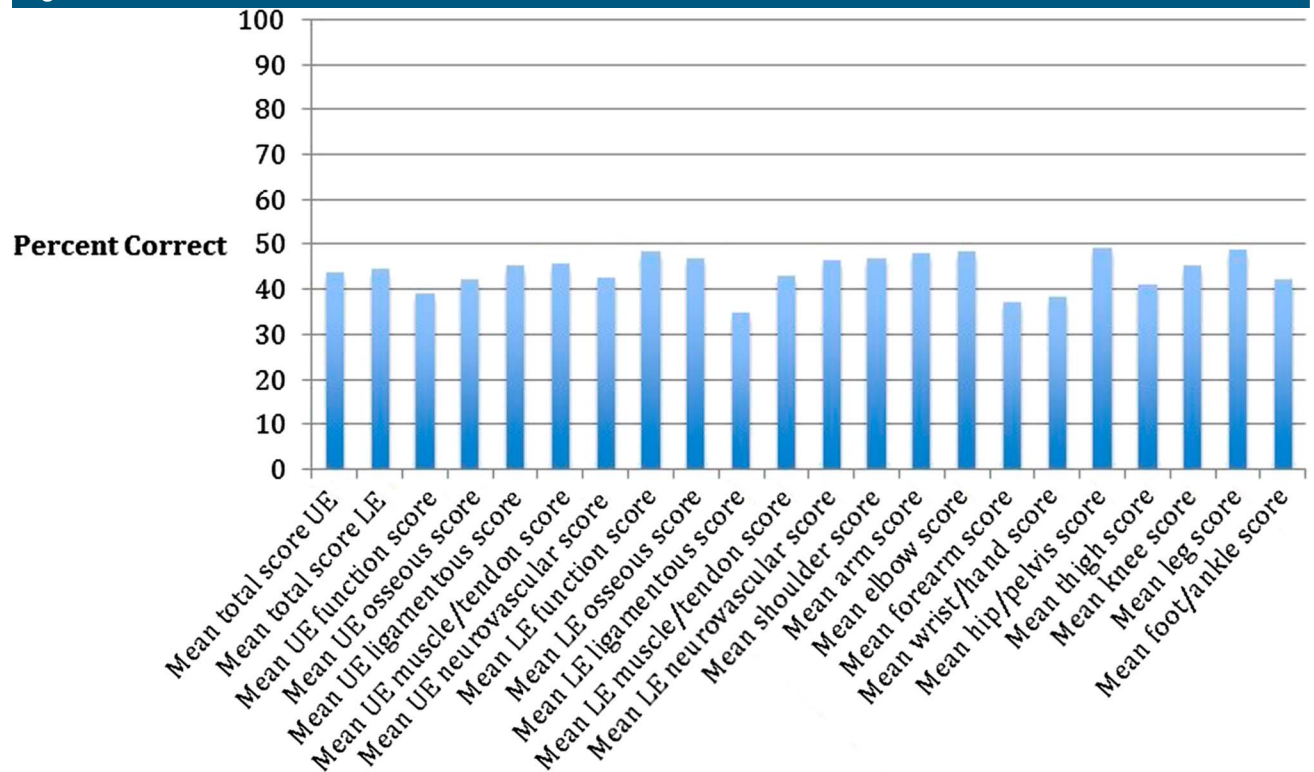
The results of the objective portion of the study are sobering and similar to those presented in the limited number of prior reports previously

Table 5**Availability and Preferences for Methods of Anatomic Instruction**

	Preference Rating 1–6 (Low Score Indicating Higher Preference)	Percent Reporting Method as Being Available at Their Medical School
Dissection	1.8	96.6%
Prosection	3.0	87.3%
Didactics	2.9	97.5%
Models	4.1	90.3%
Radiographic/topographic	4.3	81.9%
Computer simulation	4.8	62.4%

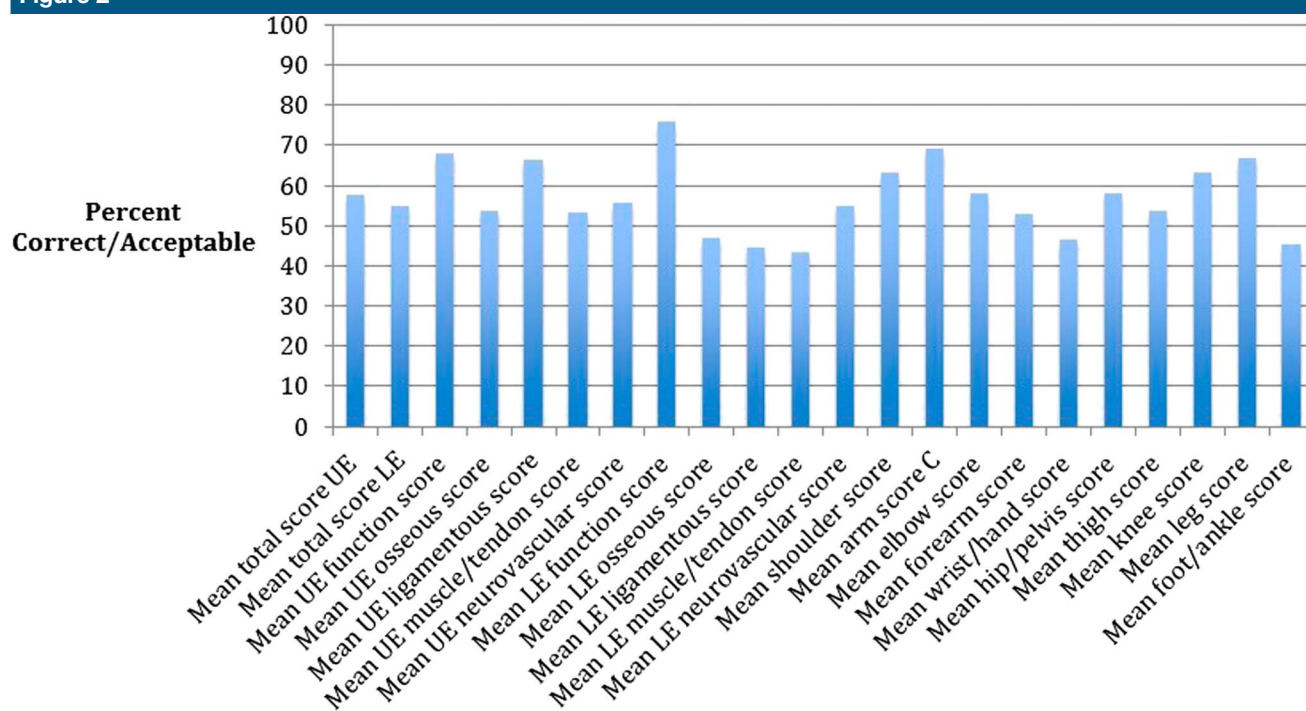
cited. Regardless of which region of the extremities and which anatomic concept was analyzed, students performed poorly. The large sample size and national-level scale of the sample from applicants from at least 92

medical schools from all regions of the country emphasize the systemic nature of the problem. The knowledge gap is not a small one and not isolated to a particular group of students. The needed solution is thus not

Figure 1

Mean correct scores for the various upper and lower extremity subcategories. LE = lower extremity, UE = upper extremity.

Figure 2



Mean correct and acceptable scores for the various upper and lower extremity subcategories. UE = upper extremity, LE = lower extremity.

Table 6

Correlations With Objective Anatomy Scores

Correlations to Mean Total Score	Pearson Coefficient
MCAT	0.21
USMLE 1	0.27
USMLE 2	0.27
Rating of "adequacy of education"	0.14
Rating of "time dedicated to anatomic education"	-0.19
Rating of "level of importance medical school placed on anatomy"	0.21

MCAT = United States Medical Licensing Examination, USMLE = United States Medical Licensing Examination.

a simple patch applied to the current educational system, but rather a complete reconceptualization of the anatomic preparation of orthopaedic applicants.

The purpose of the current study was to define the problem, and from it, no definitive recommendations on needed curricular changes can be made. Such statements would require

prospectively observed curricula changes and measurements of positive outcomes from them. Despite this, the authors would suggest the following.

Medical school curriculum on a national (and international) level is unlikely to change to conform to the needs of orthopaedic residencies. The influx of new medical knowledge is immense and will continue to vie with

anatomy in medical school syllabi. In addition, one could argue that medical schools may not be the forum for a detailed instruction in musculoskeletal anatomy. Obviously, the majority of students in medical schools go on to specialties that do not require such a comprehensive knowledge of musculoskeletal anatomy, and in fact, hours of instruction in this may rightly be viewed as a poor use of time. As such, the burden of responsibility for providing a complete anatomic education will and perhaps should fall to orthopaedic residencies. We would thus suggest that all orthopaedic residencies accept this position and make explicit efforts to address this educational deficiency. Specifically, we would suggest that all residents be exposed to a comprehensive, dissection-based instruction in musculoskeletal anatomy for which they are explicitly held accountable and evaluated. Such instruction should occur most heavily early during the

intern year and be reinforced repeatedly throughout residency.

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